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| | Filing Date | 11/21/2003 | |
| | First Named Inventor | Terry R. Galloway | |
| | Art Unit | 1745 | |
| | Examiner Name | | |
| Total Number of Pages in This Submission | 24 | Attorney Docket Number | 3178-12 |

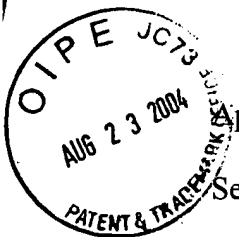
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| Signature | <i>Mary M. Padilla</i> | Date | 08/19/2004 |

This collection of information is required by 37 CFR 1.5. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to 2 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Terry R. Galloway

Serial No.: 10/719,504

Filed: November 21, 2003

For: PROCESS AND SYSTEM FOR
CONVERTING CARBONACEOUS
FEEDSTOCKS INTO ENERGY
WITHOUT GREENHOUSE GAS
EMISSIONS

Art Unit: 1745

Primary Examiner: Stephen J. Kalafut

Atty. Docket: 3178-12

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(37 C.F.R. § 1.8(a))**

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8/19/04
Date

Mary M. Padilla
Mary M. Padilla

PETITION TO MAKE SPECIAL BY ACCELERATED EXAMINATION

(37 C.F.R. § 1.102(C) AND M.P.E.P. § 708.02(V and VI))

Mail Stop Petition
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Applicants hereby petition to make this application special by accelerated examination. All pending claims of the above-referenced application are directed towards a single invention. Accompanying this petition is:

1. A Statement of Facts in Support of Petition to Make Special by Accelerated Examination;
and
2. No fee accompanies the filing of this Petition pursuant to 37 C.F.R. § 1.102(c).

The Commissioner is hereby authorized to charge any additional fees which may be required in this application under 37 C.F.R. §2.6, or credit any overpayment to Deposit Account No. 13-0201. A copy of this letter is enclosed.

Respectfully submitted,

Dated: 8-18-04


Richard A. Dannells
Reg. No. 22,654

August 18, 2003
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8/19/04
DateMary M. Padilla
Mary M. Padilla**STATEMENT OF FACTS IN SUPPORT OF PETITION TO MAKE SPECIAL BY
ACCELERATED EXAMINATION****(37 C.F.R. § 1.102(c) AND M.P.E.P. § 708.02(V and VI))**

Mail Stop Petition
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

I, Terry R. Galloway, have an address at Intellergy Corporation, 6801 Sherwick Drive, Berkeley, CA 94705-1744, am the sole inventor and owner of the assignee of the above-identified application, and hereby make the following statements of facts in

support of a Petition to Make Special by Accelerated Examination according to the rules set forth in M.P.E.P. section 708.02.

1. The above-identified application qualifies to be advanced out of turn for examination and to have this application be accorded "special" status based on the conditions set forth in M.P.E.P. section 708.02, paragraph V "Environmental Quality" and paragraph VI "Energy."

2. Specifically, M.P.E.P. section 708.02, paragraph V "Environmental Quality" states that the USPTO "will accord "special" status to all patent applications for inventions, which materially enhance the quality of the environment of mankind by contributing to the restoration or maintenance of basic life-sustaining natural elements, i.e., air, water, and soil."

3. Upon information and belief, the invention described and claimed in the above-identified application will materially enhance the quality of the environment of mankind by contributing to the restoration and maintenance of basic life-sustaining quality of each of air, water, and soil. Specifically, the invention described and claimed in the above-identified application is a process and system in which (1) a carbonaceous waste stream, such as medical, municipal, industrial, hazardous wastes and the like, is destroyed and converted in a waste conversion reactor to hydrogen-rich synthesis gas (syngas) that does not result in polluting emissions to the air, water or soil, (2) at least a portion of this syngas is electrochemically oxidized in one side of a high temperature-type fuel cell (i.e., molten carbonate or solid oxide) to produce carbon dioxide and water, and (3) this carbon dioxide from the fuel cell is recycled to the waste conversion reactor so that the carbon dioxide is reacted to make more syngas for use to make chemical co-products that contain carbon and thus sequester what would otherwise be a greenhouse gas emission. This process and system eliminates the need for processes and systems in the prior art that burn such waste, which have been a source of serious toxic air emissions. This process and system also eliminate need for the processes and systems in the prior art that dump

such waste into common landfills, with their health-damaging problems of soil contamination and leakage of rainwater through the landfill into underground aquifers, which contaminate drinking water wells.

4. M.P.E.P. section 708.02, paragraph VI "Energy" states that the USPTO "will, on petition, accord "special" status to all patent applications for inventions which materially contribute to (A) the discovery or development of energy resources, or (B) the more efficient utilization and conservation of energy resources. Examples of inventions in category (A) would be developments in fossil fuels (natural gas, coal, and petroleum), hydrogen fuel technologies, nuclear energy, solar energy, etc. Category (B) would include inventions relating to the reduction of energy consumption in combustion systems, industrial equipment, household appliances, etc."

5. Upon information and belief, the invention described in this application falls within both category (A) and category (B) of M.P.E.P. section 708.02, paragraph VI, because this invention qualifies as a new "development in energy resources" by generating electricity through the conversion of non-polluting carbonaceous waste stream, a large new energy source that is presently of insignificant use, into electrical energy in accordance with category (A) and because this invention relates to "the reduction of energy consumption in combustion systems, industrial equipment, household appliances, etc." due to the fact that it conserves energy sources by the production of energy at a nearly double the efficiency of past combustion practice in accordance with category (B). Specifically, the process and system described in this application electrochemically reduces an oxygen-containing gas, e.g. air, in another side of the fuel cell referred to in paragraph 3 above to produce electrical energy at from 50% to 78% efficiency (chemical energy in to electrical energy out). Efficiencies as high as 78% are possible using a Brayton cycle turbine that uses the hot gases from the fuel cell exit to generate another 25% or so electricity. Thus, the waste-to-energy efficiency is more than double that typically attained through the combustion of the waste to raise steam and generate electricity via turbo-generators. This higher efficiency conserves an energy source such

electricity via turbo-generators. This higher efficiency conserves an energy source such as organic waste or other biomass stream.

6. A representative sample of municipal waste from Ontario, Canada has been shown to have a 90% volume reduction with a very practically short residence based on a laboratory scale rotary kiln of the type disclosed and claimed in the above-identified application; see Terry R. Galloway, et al., "*Hydrogen From Steam/ CO_2 Reforming Of Municipal Solid Waste*," pp. 10-14, presented April 27-30, 2004, attached hereto as Exhibit I.

7. Upon information and belief, laboratory rotary kiln and the fuel cell are very scalable pieces of equipment that supports the development of both small and large (utility scale) non-polluting systems for the generation of electricity.

Dated: _____

August 18, 2004


Dr. Terry Galloway



Hydrogen From Steam/CO₂ Reforming Of Municipal Solid Waste

T. Galloway & J. Waidl¹
J. Zwierschke & E. Dueck²

1. Abstract:

To preserve the environmental and geopolitical advantages of the Hydrogen Economy, the processes to generate the hydrogen must involve renewable energy sources. Hydrogen produced using wind, solar, and waste sources are classified as renewable hydrogen (reH₂). This paper focuses on using widely available municipal solid waste (MSW) to produce reH₂ by means of a new process involving steam and carbon dioxide reformation.

A pilot rotary kiln reformer was used to process MSW using steam and carbon dioxide (CO₂) to produce the hydrogen-rich syngas. The tube was radiantly heated to 900°C, and was rotated at 5 rpm. The H₂ and CO levels peaked at 40 minutes. Integrating these data (i.e. as the MSW moves along the commercial kiln), the syngas is determined to have a steady composition around 40% H₂, 6% CO, with balance being steam and CO₂. The final residue had a density at 0.8 gm/cc and had a mousey grey color, also indicating the absence of residual fixed carbon remains.

The successful result of this test showed that steam/CO₂ reforming can achieve the desired volume and mass reduction in a reasonable residence time. Based on these data, a 20 tonne/day steam/CO₂ reforming small-scale plant is being designed with the syngas feeding a molten carbonate fuel cell. In this plant the CO₂ produced from the anode of the fuel cell is recycled back into the reformer so that it can be part of the steam/CO₂ reforming chemistry to produce added syngas which produces carbonaceous co-products for sale. In this way, the carbon in the MSW is sequestered and not released into the atmosphere to add to the greenhouse gas problem. From this 20 tonne/day scale of operational experience and process data, the full-scale, 250 tonne/day plant will be designed for accepting the entire MSW stream from Toronto. This success will eliminate the trucking of Toronto waste at 130-140 trucks/day to Michigan for land disposal. The initial look at the economics suggests an attractive 5-year payback for the plant can be achieved.

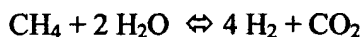
1. Intellergy Corp., Berkeley, CA;
2. EnQuest Power Corp. & ENCOR Niagara, St. Catharines, Ont., Canada

Keywords: Steam/CO₂ Reforming, Renewable Hydrogen, Intellergy

2. The Chemistry of Steam/CO₂ Reforming

FIG. 1 is a plot of the commercial steam reforming of methane that is a well known commercial process and is the principal process for manufacturing hydrogen gas in refineries for use in petroleum hydro-cracking and hydro-reforming process steps as well as manufacturing hydrogen gas as a commodity sold in the marketplace. Standard nickel catalysts are used for this conversion in order to lower the reactor tube temperatures so that less expensive alloys can be used and their process lifetime extended.

First, some explanation of these computed results is helpful. The calculations are performed by the method of Gibbs Free Energy Minimization to yield gas compositions at thermodynamic equilibrium from the lowest temperature of 200°C up to 2000°C. The chemistry is started by placing methane (CH₄) and steam (H₂O) at one atmosphere in the gaseous (subscript, g) state in a vessel at 200°C. We wait for a very long time for the compounds to react slightly and form a small quantity of hydrogen (H₂) and carbon dioxide (CO₂). This composition of the gas mixture is that which occurs if the chemical kinetics were fast enough to allow the reaction to reach completion in the time allotted. There are actually two reactions that are occurring simultaneously here:



As soon as the H₂ and CO₂ are formed, the “Water gas shift reaction” forms H₂O and CO by:



In this way, the two reactions interact according to each of their free energy driving forces to arrive at an equilibrium balance, and the final compositions are shown in the FIG. 1. As the temperature is raised, the equilibrium shifts to forming H₂ and CO.

Practically speaking; however, commercially one cannot wait long periods of time for the slow chemical kinetics at 200°C to reach the equilibrium composition. The gas composition curves are achieved more quickly with less residence time when active surface catalysts are used to impart extra energy into the gases to encourage them to react more quickly. As the temperature is increased, the kinetic velocities and energies are increased by the increased kinetic activities of the gases carrying more energy in their collisions and forming other compounds more quickly. Eventually, as the temperature is increased significantly to say 600°C, the kinetics become so fast that no active surface catalyst is needed. Thus, the gas compositions shown in FIG. 1 can be achieved at temperatures above 600°C without the use of catalysts since the approach to thermodynamic equilibrium can be achieved in reasonable residence times. To make commercial H₂, the commercial embodiment carries out the gas-phase chemistry inside of catalyst-coated tubes or tubes filled with catalyst-coated ceramic beads. These

tubes are heated externally by means of very hot flue gas from a gas-fired furnace, sometimes using oxygen-enriched combustion air.

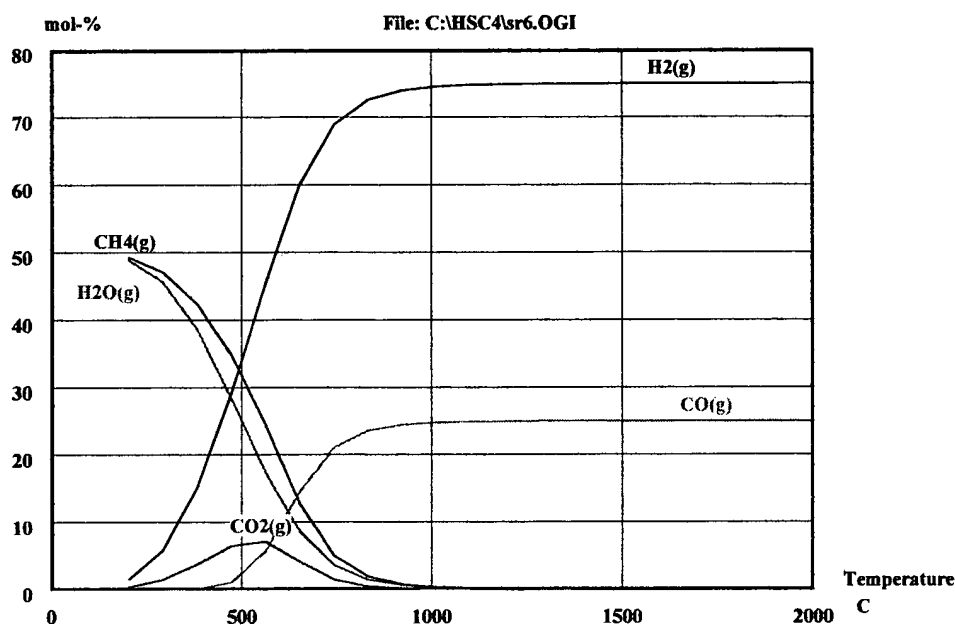


FIG. 1 is a plot of the commercial steam reforming of methane to make syngas consisting of hydrogen and carbon monoxide. (sr6)

As the molecular complexity of the feed hydrocarbons increase, the temperatures have to be increased to levels well above 600°C in order to approach their chemical thermodynamic equilibrium composition without the enhancing and accelerating effect of catalysts. In fact, we find that above 700°C is practically where catalysts are no longer needed when dealing with organic wastes [1-10].

Commercial gasification processes for coal, coke, petroleum, organic waste, etc. use high pressure, entrained flow, partial oxidation, such as the Texaco gasifier or the Shell gasification process [4-5]. These large gasification reactors operate at low enough temperatures that more cost-effective alloys can be used at high pressures for these commercial gasification vessels. When low pressure gasification catalytic beds are often used, for temperatures of 700°C and below, the wastes must be carefully selected so the catalysts are not easily poisoned when waste is used as feedstock, because of halogen and heavy metal contaminants. But a better solution is to work at higher temperatures without catalysts and avoid this problem of wastes and catalyst poisoning.

Now introducing high temperature fuel cells [11-19] into the process, FIG. 2 shows the steam/CO₂ reforming of a mixture of methane and fuel cell-produced carbon dioxide added into the feed at 20%. Again at high temperatures over 700°C, the syngas compositions shown are achieved without the need for

catalysts. Comparing FIG. 1 and FIG. 2 beyond 800°C, it is noted that the hydrogen content is slightly lowered by the presence of increased carbon monoxide and water that are formed and by the residual carbon dioxide, since all three act as significant diluents in the formed syngas product, diluting the hydrogen. In fact, the carbon dioxide has no positive effect in the reaction, other than that it is consumed so that it is not released to the environment.

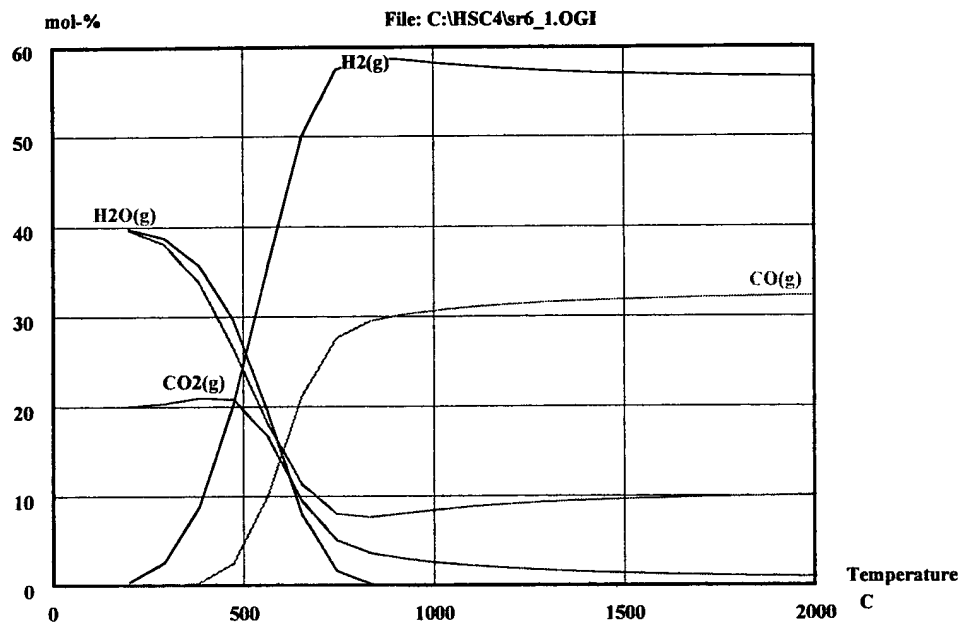


FIG. 2 shows a plot of the steam reforming of a mixture methane and fuel cell produced carbon dioxide at 20% in the feed. (sr6_1)

These effects are even more exaggerated in FIG. 3 and FIG. 4 at carbon dioxide concentrations of 25% and 30%, respectively. In the latter case, the hydrogen concentration is dropped from the higher hydrogen of 58% down to 46.5% with carbon dioxide increased to 30% in the feed. But most importantly, in all these cases with increased carbon dioxide, the hydrogen is found to drop gradually with increasing temperatures over 800°C where the thermodynamic equilibrium is achieved without the use of a catalyst.

Increasing the fraction of steam in the feed, as shown in FIG. 5 does not correct this problem, as one would have first thought. This situation, under conventional previous thinking, dictated that with the use of lower temperature aided by the use of catalysts, the catalysts were strongly preferred with natural gas to maximize the hydrogen product concentration desired. Such was the dilemma faced in the past.

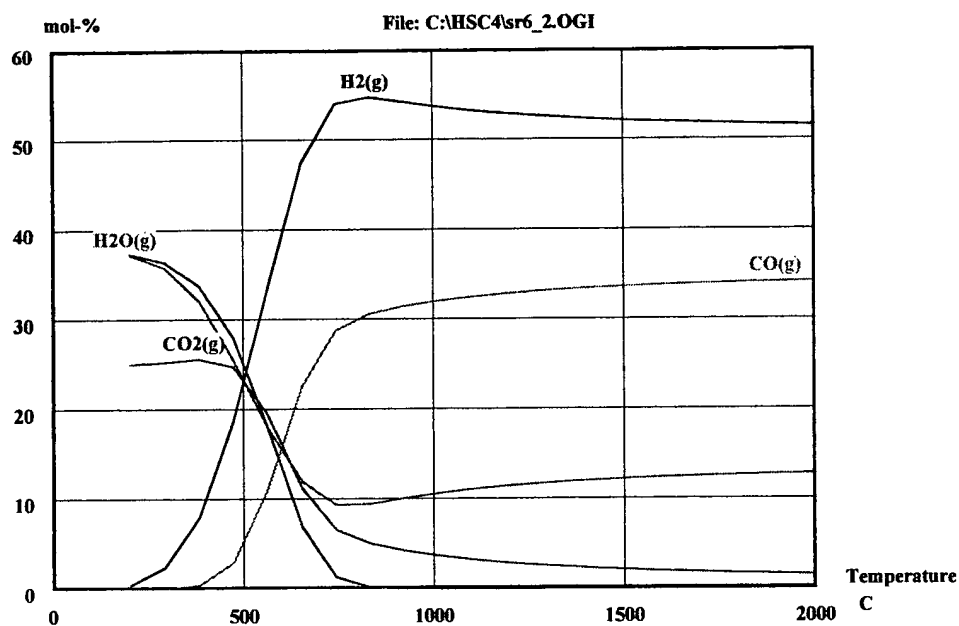


FIG. 3 shows a plot of the steam reforming of a mixture methane and fuel cell produced carbon dioxide at 25% in the feed. (sr6_2)

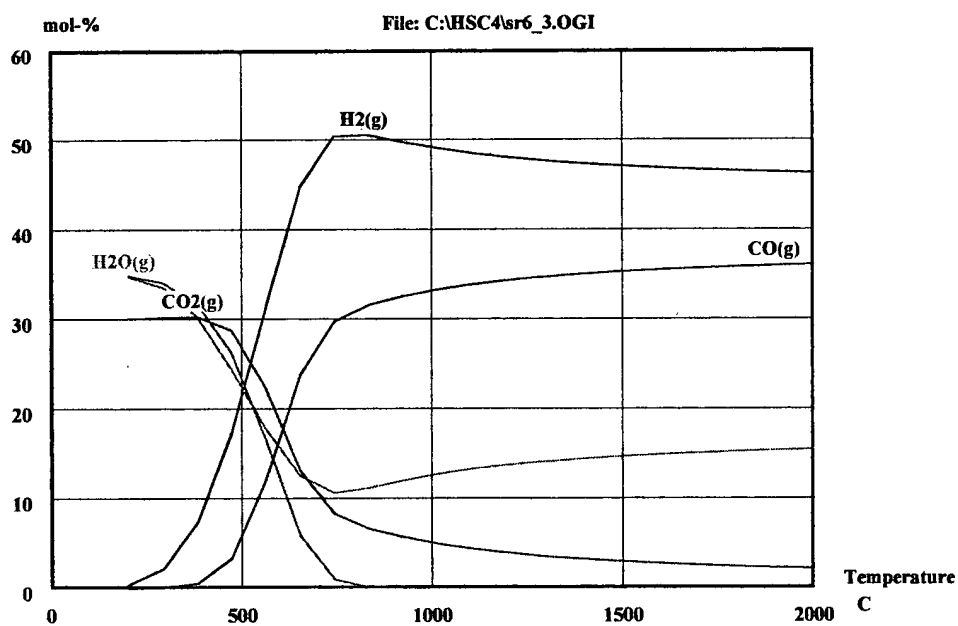


FIG. 4 shows a plot of the steam reforming methane and fuel cell produced carbon dioxide at 30% in the feed. (sr6_3)

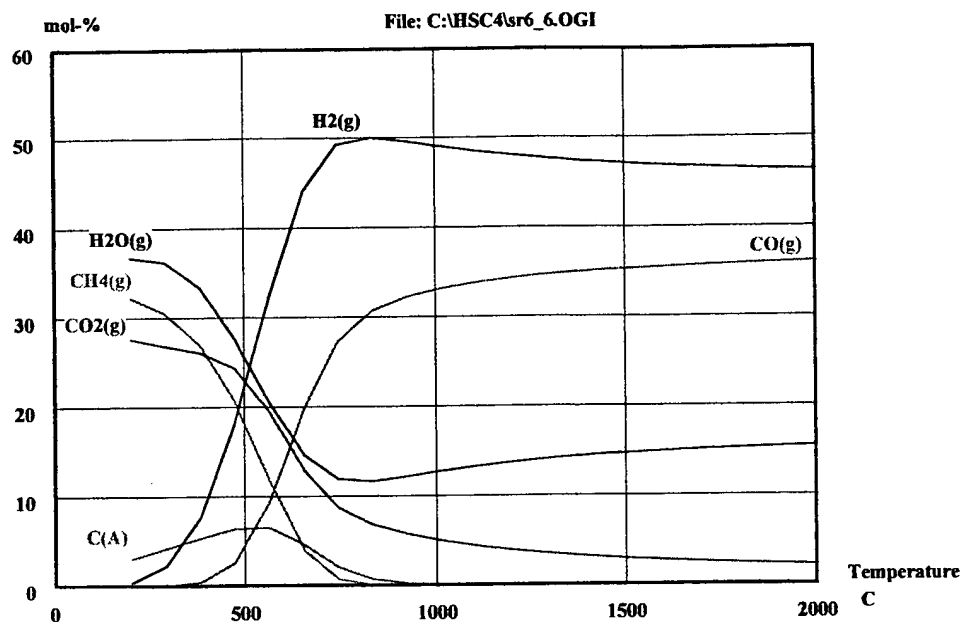


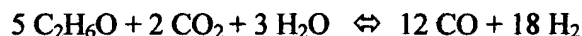
FIG. 5 shows a plot of the steam reforming methane and fuel cell produced carbon dioxide at 27.6% in the feed with elevated steam at 36.7%. (sr6_6)

But surprisingly, once departing from conventional past thinking, there is a much-preferred solution to optimize this fuel cell link that has been overlooked and not exploited previously. It involves using elevated steam feed and CO₂ simultaneously with complex waste streams that have higher carbon/hydrogen ratios than simple methane. This approach appears at first to be contrary to common thinking and conventional practice, that suggests that to achieve optimum hydrogen concentrations at high temperature, the worst option is to INCREASE the carbon content of the feed. But this simplistic logic is, in fact, very wrong, as shown here and in our patent filings.

Consider the very simplified chemical reaction with the waste stream fairly characterized entirely by carbon:



This is already 40.5% by volume hydrogen (i.e. mole percent). This is the rough optimum, maximizing hydrogen content. Varying the stoichiometric quantities of the reactants produces less than optimum hydrogen, but maintains as constant syngas mole volume, which is a very desirable end result. Note, that the addition of CO₂ reduces the requirements for water below stoichiometric requirements. In fact, there is an optimum combination of using both CO₂ and water in achieving target H₂/CO ratios, while maintaining high levels of syngas product. A MSW example might be:



A generalized chemical reaction can be written for most carbonaceous feedstocks as expressed by the generalized empirical formula, $\text{C}_a\text{H}_b\text{O}_c$:



The H_2/CO ratio can be optimized by the right combination of CO_2 & H_2O for a given waste feed mixture characterized by the empirical formula, $\text{C}_a\text{H}_b\text{O}_c$. Note, that the amount of H_2O needed is reduced below its stoichiometric requirements $(5a-5c)$ for conventional steam reforming by the “D” amount of CO_2 needed, since the stoichiometric coefficient on H_2O is now $(5a-5c-\text{D})$.

Also, to help us adjust the H_2/CO ratio needed for Fischer-Tropsch synthesis of useful chemical co-products to sequester the carbon and avoid greenhouse gas emissions, examining this H_2/CO ratio is helpful, since it is expressed as:

$$\frac{\text{H}_2}{\text{CO}} = \frac{5(a + 0.5b - c) - \text{D}}{5a + \text{D}}$$

Note, for a given carbonaceous feedstock with the empirical formula, $\text{C}_a\text{H}_b\text{O}_c$ one can adjust the amount of CO_2 , “D”, to satisfy the Fischer-Tropsch synthesis requirements.

To achieve higher hydrogen concentrations at high temperature to drive the fuel cells, increased feedstock hydrogen content together with an excess steam below stoichiometric levels, $(5a-5c-\text{D})$, is allowed, combined with the recycled fuel cell carbon dioxide, D. This provides the chemistry at thermodynamic equilibrium that achieves a higher hydrogen-rich syngas that remains high and steady in hydrogen over a broad high temperature range up to and beyond 1300°C without catalysts.

FIG. 6 shows a plot of the steam reforming of a mixture of a typical industrial solvent waste (acetone, formaldehyde, methanol, dimethylbenzene, butanol, trichlor, and perchlor). Even further improvements can be made, surprisingly, as are shown in FIG. 7, by increasing the recycle $\text{CO}_2/\text{H}_2\text{O}$ ratio from the 0.0 in FIG. 6 up to 0.5. This added CO_2 was from the fuel cell. The steam used in FIG. 7 is actually a DECREASE to 60% in the amount of steam consumption in the process, with the advantage of the steam/ CO_2 reforming reactor being able to accept more CO_2 , contrary to conventional thinking.

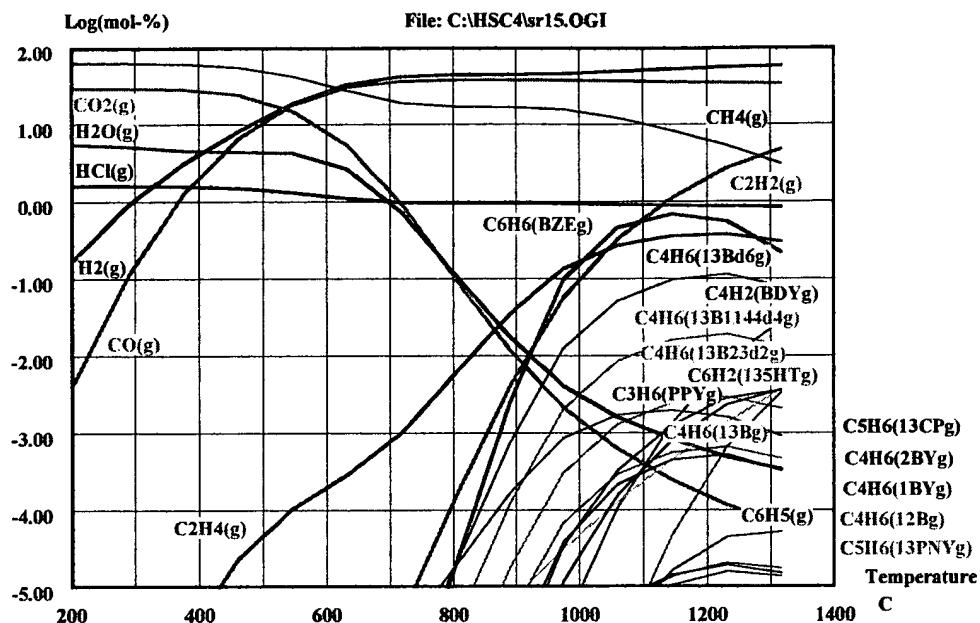


FIG. 6 shows a plot of the steam/ CO_2 reforming of a mixture of typical industrial waste, no fuel cell-produced CO_2 added in the feed with super-stoichiometric steam at 60% achieving high hydrogen but dirty syngas. (sr15)

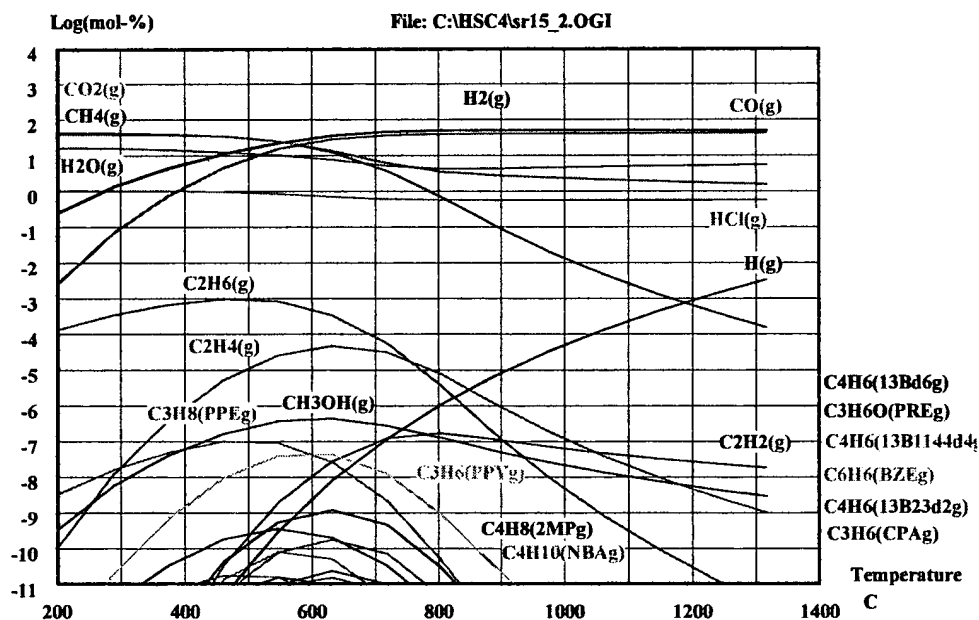


FIG. 7 Steam/ CO_2 reforming a mixture of a typical industrial waste and fuel cell produced carbon dioxide at 20% added in the feed with super-stoichiometric steam at 60% achieving high hydrogen and the cleanest syngas. (sr15_2)

Looking at FIG. 7 at 700°C or 1200°F, the syngas product composition starts at the highest with H₂, hydrogen, at 50.0%; then CO, carbon monoxide at 42.4%; H₂O, water at 5.36%; CO₂, carbon dioxide at 1.73%; HCl, hydrogen chloride gas at 0.57% ppm; •H, hydrogen radical at 13 ppm; CH₄, methane at 4.31 ppm; C₂H₂, acetylene at 24 ppb; C₂H₄, ethylene at 3 ppb; with all other compounds at levels below 0.05 ppb. Note: this is about 10 million times cleaner or lower in minor contaminants than in FIG. 6.

Both of these improvements are economically attractive commercially. This yields a H₂/CO around 1.18, that is a syngas composition more amenable to making more valuable chemical co-products than methanol (selling only @ 50¢/lb), for example, that requires a H₂/CO of 2.0 for its synthesis. Thus, the addition of shift reactors to adjust the H₂/CO upward or downward are not required – a further economic advantage of this new process. The advantage of the current method is that by recycling CO₂ and adjusting the levels of CO₂ versus H₂O, an optimum H₂/CO ratio from about 1.0 to about 1.5 can readily be achieved to match the end products required for either the Fuel Cell or Gas to Liquid conversions and equally as important to achieve the ever-elusive sequestering of near 100% of the greenhouse gas, CO₂. The process equipment designed to accomplish this chemistry most economically is a slightly inclined horizontal rotary kiln that is heated externally. These are called “indirectly heated rotary kilns.” See FIG. 8.

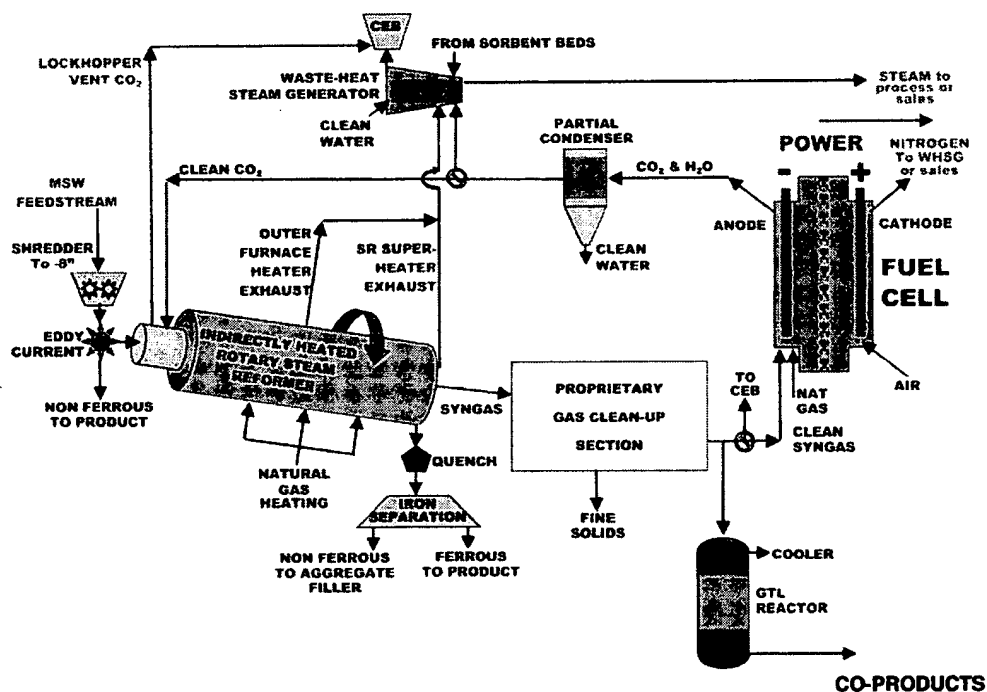


FIG. 8 Shows the indirectly fired steam/CO₂ rotary kiln and its interface to the fuel cell.

The slight inclination encourages the feedstock to move axially along the rotary kiln away from the feed end as it is rotated slowly. The carbonaceous feedstock or waste near room temperature is introduced into one end wherein the kiln temperature may be at 400°C, and it is subjected to increasing temperatures as it moves along the kiln toward the exit end that would be preferably around 900 to 1200°C. The higher temperatures would be needed to accomplish the high levels of destruction required by U.S. EPA law should there be listed hazardous waste contaminants in the waste feedstock. For recovery of metals and glass for possible recycling, these solids would be removed from the kiln before they are melted. Such a conceptual drawing of this contemplated waste feed section to the rotary kiln is shown in FIG. 8. This is a slightly inclined rotary kiln where the residual solids are removed at the solids exit from the rotary kiln as the location in kiln reaches about 400°C along its length before they are melted there is a slipstream portion of the syngas that feeds the Fischer Tropsch synthesis unit producing the carbon-containing chemical co-product. FIG. 9 shows how the carbon balance works so that all the carbon going in as part of the waste feed leaves the process as a sequestered carbon-containing co-product for sales. These products are selected from a list of products that are never burned during their life cycle in order to insure carbon sequestering forever.

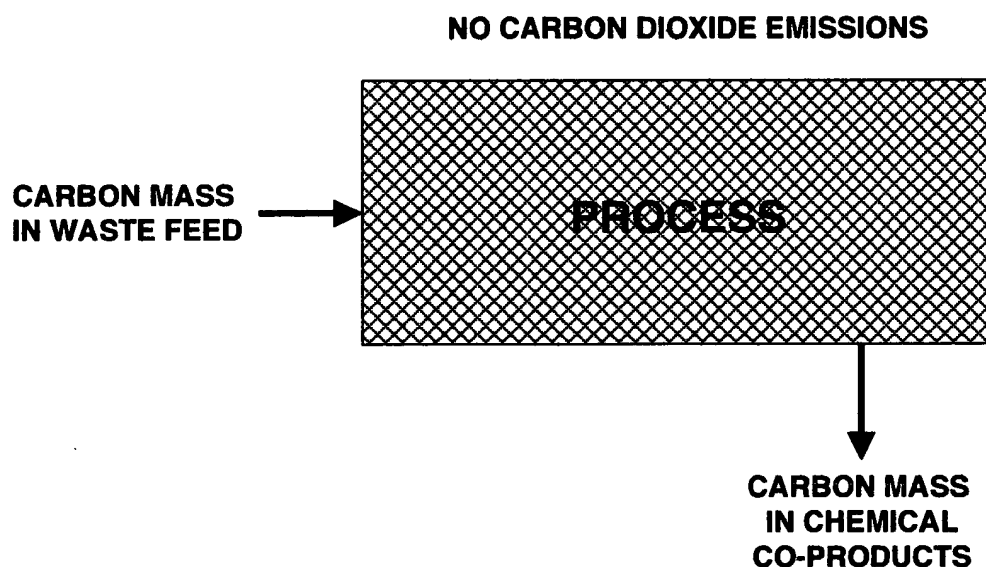


FIG. 9 Carbon balance.

3. Lab-Scale MSW Steam/CO₂ Reforming Rotary Kiln Test

The purpose of the laboratory-scale rotary kiln proof-of-principal test was to show that a representative sample of MSW could be steam/CO₂ reformed in rotary kiln to achieve a 90% volume reduction with a practically short residence time.

The MSW was sampled to obtain a surrogate sample representative of Hamilton, Ont. This MSW surrogate was submitted to a thermo-gravimetric analysis that showed an 80% mass loss in 80 minutes at 650°C (1200°F). From the shape of this curve, it could be concluded that at a slightly higher temperature and longer times, 90% mass reduction could be obtained. These tests were performed under a research contract with Shaw Environmental and Infrastructure of Knoxville, TN.

This surrogate was also subjected to Ultimate Analysis that showed on a weight basis: Carbon=47.90%, Hydrogen=6.67%, Nitrogen=2.89%, Sulfur=0.29%, Chlorine=1.62, Oxygen=30.12%, Ash=4.28%, Inerts=6.24%. The Proximate analysis showed 83.14% volatile matter, Ash=4.28%, fixed Carbon=12.28%. These tests were done by Galbraith Laboratories Inc, of Knoxville, TN.

A size-reduced (about 1 cm size pieces) surrogate sample representative of Hamilton, Ont. MSW of 230 gms in mass was placed into the lab-scale (15 cm diameter x 40 cm long) rotary kiln heated section. An image of the raw sample is shown in FIG 10.



FIG. 10 Raw sample is shown

The tube was radiantly heated to 900°C, and subjected to a flow of superheated steam produced from 6 cc/min of water to the superheater, and 1 liter/min of carbon dioxide gas. The tube was rotated at 5 rpm and contained two lengths of 6.3 mm rebar tumbled with the MSW sample to simulate the frictional effects of a much deeper bed in the large commercial kiln. FIG. 11 shows this heated section

of the lab rotary kiln about to be surrounded with the clam-shell furnace half-sections.

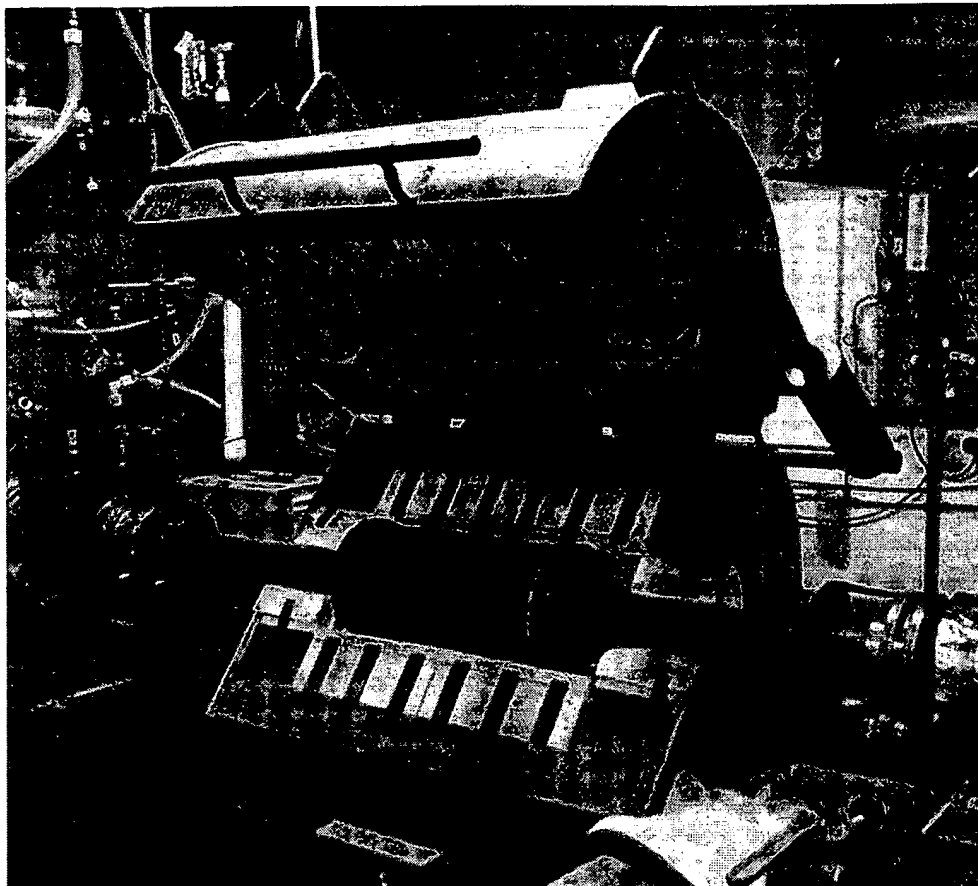


FIG. 11 Shows this heated section of the lab rotary kiln about to be surrounded with the clam-shell furnace half-sections. Sample is batch-loaded in large tube.

The test began at 11:05 am EDT where the room temperature tube was first subjected to radiant heating. By 11:27 am the tube reached 650°C with the steam/CO₂ reforming chemistry well started. By 11:50 am the syngas reached about 40vol% H₂, 7.5% CO and 5% CH₄. By 12:08 pm the 900°C setpoint was reached, at which point the remaining portion of the test continued. The CO was used as an indicator of the progress of the steam/CO₂ reforming conversion of the MSW. At about 50 minutes into the test, the CO had begun to peak at over 25%, and at 75 minutes reached 28%, and thereafter started its decline to the end of the test. The predetermined criteria for completion of the test was the exit CO declining to 5% (i.e. 1.4 % CO) of the peak reading or 2 hours at 900°C, as the carbon in the batch sample becomes depleted. At 120 minutes into the test (65 minutes at 900°C), the CO had dropped to 4.25% and by 193 minutes (130 minutes after reaching 900°C), CO fell below 1.4 % as read on the on-line monitor. At this point a Tedlar bag sample was taken to obtain the gas chromatograph confirmation. By 197 minutes (134 minutes after reaching

900°C), the GC showed 0.3% CO, well below the 1.4% cutoff point desired; so the test was stopped. FIG. 12 shows the clam-shell furnace halves opened and put away and the central tube glowing cherry red as it began its air cooling. After some time allowed for air cooling, the entry and exit tubes were water cooled and eventually (around 2:43 pm) the tube was opened to collect the final residue and determine its weight at 28.3 gms and density at 0.8 gm/cc, non-compacted.

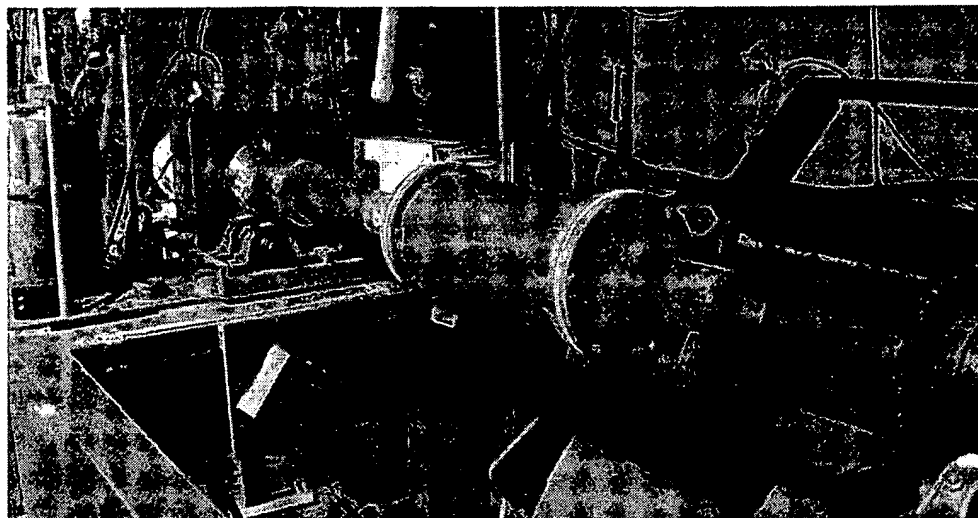


FIG. 12 Shows the clam-shell furnace halves opened and put away and the central tube glowing cherry red as it began its air cooling

The volume and mass reduction from the MSW initial volume of 2.4 liters (density = 0.096 gm/cc) non-compacted was calculated to be 98.5% VR or 87.8% mass reduction. Thus, we find the VR of 90% was achieved and the test was successful. Some compacting tests will change this VR value somewhat, but will be well over the 90% VR. FIG 13 shows the vial containing the final residue product. Note that it is a fine powder with no indication of the black hollow skeletal remains commonly called "Pyrochar," indicating completion of the reaction. Note that the color is a mousey grey, also indicating the absence of residual fixed carbon remains. The final residue consists mostly of the inorganic fraction, comprising almost entirely the mineral kitty litter sorbent in the original waste feed.

The successful result of this proof-of-principle test showed that steam/CO₂ reforming using added CO₂ but less than molar excess superheated steam can achieve the desired VR and MR in a reasonable residence time. The steam/CO₂ reforming reactions were definitely past completion at the end of the test indicating that there may be room to either decrease the temperature from 900°C or reduce the retention time from 134 minutes or both. Further test work is planned to decrease operating design criteria below 900°C and 2.25 hours.

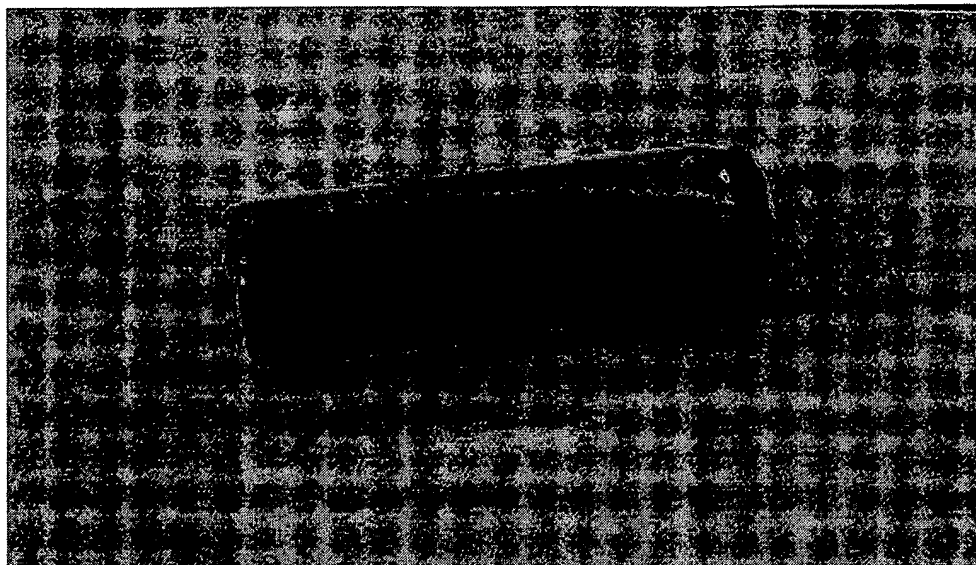


FIG. 12 Shows the vial containing the final residue

4. Proforma Economic Analysis

Using the above-demonstrated pilot-scale results, a feasibility analysis was done, costing all the capital in FIG. 8, process control, labor requirement, and cost of money. Based on these data, a 20 tonne/day steam/CO₂ reforming small-scale plant was scoped with the syngas feeding the fuel cell. In this plant, the CO₂ produced from the anode of the fuel cell is recycled back into the reformer so that it can be part of the steam/CO₂ reforming chemistry to produce added syngas to synthesize food-grade paraffin as the product which is sold. In this way, the carbon in the MSW is sequestered and not released into the atmosphere to add to the greenhouse gas problem. From this 20 tonne/day scale of operational experience and process data, the full-scale, 250 tonne/day plant will be designed for accepting the entire MSW stream from Toronto. This success will eliminate the trucking of Toronto waste at 130-140 trucks/day to Michigan for land disposal. The initial look [20-24] at the economics suggests an attractive 5-year payback for the plant can be achieved.

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